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WATER VAPOR PERMEANCE OF POLYOLEFIN BALE BAGGING

Shay L. Simpson
Texas A&M University
College Station, TX
Andrew G. Jordan
Memphis, TN
Stephen W. Searcy
Texas A&M University
College Station, TX

Abstract

Cotton bale bagging materials currently used in the cotton industry, polyethylene (PE) film and fully-coated woven polypropylene (WPP) were perforated and tested using ASTM E 96 – Standard Test Methods for Water Vapor Transmission of materials. Permeance characteristics are reported for materials in metric units, g/Pa·s·m^2, and inch-pound units, Perm. Perforations were made using two pin sizes, 0.787 mm and 0.914 mm, at six hole densities, 0.2, 0.4, 0.8, 1.6, 16, and 32 holes per square inch (hpsi). Permeance values ranged from 0.7 to 25 Perms for WPP and 0.3 to 27 Perms for PE. The permeance of WPP was higher than PE at each condition tested below 16 hpsi. Permeance per pinhole was evaluated and for both materials, the values decreased with increasing pinhole density. The pinhole size difference did not result in significantly different permeance values for WPP and PE.

Background

Specifications for cotton bale bagging are developed by the Joint Cotton Industry Bale Packaging Committee (JCIBPC) of the National Cotton Council. Over the past 38 years cotton bales have improved in appearance and protection afforded by the package – both ties and bags. Bagging materials have evolved from jute wrap and strip-coated woven polypropylene (WPP), having great air and water vapor permeability, to polyethylene (PE) film and fully-coated WPP. Permeability characteristics of the later materials may hinder adequate movement of air and moisture in or out of the bag for basic protection of lint. Excess water vapor trapped in the bale could lead to condensation and mold. A lack of adequate water vapor transmission through the bagging into the bale is unacceptable for textile manufacturers that require lint to stabilize at 6-7 percent moisture content for the opening process.

Researchers at Texas A&M University in the Biological and Agricultural Engineering Department are working with National Cotton Council staff to determine a method for achieving adequate water vapor transmission. Standard Test Methods for Water Vapor Transmission of Materials, ASTM E 96 *Procedure C*, was employed to test PE and WPP materials with a variety of puncture pin sizes and hole densities. Water vapor transmission and permeance are important performance evaluations of bale bagging.

Permeance is the amount of water vapor that passes through an area of material per time at a differential vapor pressure. Permeance is calculated as follows:

$$Permeance = \frac{WVT}{\Delta p} = \frac{(G/t)/A}{S(R_1 - R_2)} \quad (1)$$

where: *Permeance* = *g/Pa·s·m^2 (Perm, grains/in.Hg·h·ft^2)*
WVT = *Water Vapor Transmission, g/h·m^2 (grains/h·ft^2) = (G/t)/A*
Δp = *vapor pressure difference, mm Hg (in. Hg)*
G = *weight change, g (grains)*
t = *time during which G occurred, h*
G/t = *slope of the straight line, g/h (grains/h)*

A = *test area (cup mouth area),* m^2 (ft^2)
S = *saturation vapor pressure at test temp, mm Hg (in. Hg)*
R1 = *RH at the source (chamber), fraction*
R2 = *RH at the vapor sink, fraction.*

Procedures

Materials and methods used for preparing bagging samples for testing in ASTM E 96 Procedure C follow. An accurate and precise hole was created using a hole punch machined at the Biological and Agricultural Engineering Department shop and pins from VP Scientific that were ground and polished to a point (figure 1). The punch allowed for varying hole densities from 0.2 holes per square inch (hpsi) to 50 hpsi depending on the number of pins placed in the pin bar. In this study, six hole densities were used, 5.0, 2.5, 0.25, 0.12, 0.06, 0.03 holes/cm^2 (32, 16, 1.6, 0.8, 0.4 and 0.2 holes/in^2, hpsi). Each punch process provided the same pin angle of entry into the bagging sample. The resulting holes should be uniform, but as the holes were punched manually, uniformity is less than could be achieved with an automated process. Four pin diameters of 0.356 mm, 0.787 mm, 0.914 mm, and 1.58 mm were purchased, of which only the two mid-sizes were used for this study.

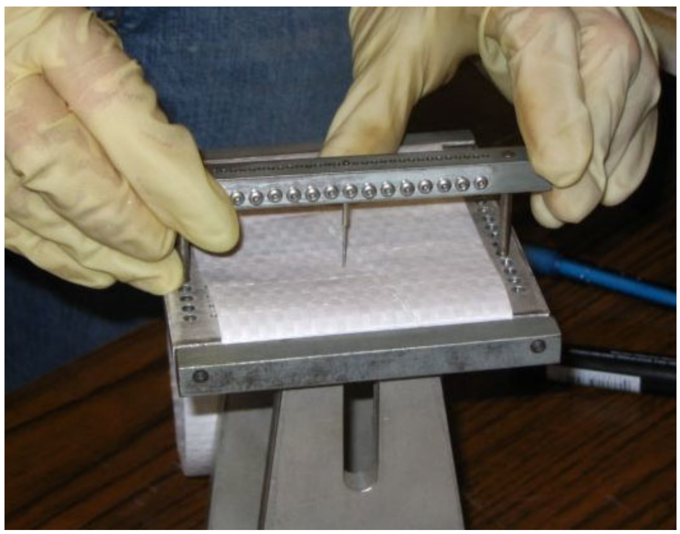

Figure 1. Pin punch and pin size 0.914 mm used to create uniform holes in WPP sample.

Nine Model 68-1 vapometers from Thwing Albert Instrument Company were filled with anhydrous calcium chloride, a desiccant for providing a vapor sink. Samples were cut from the punched bagging material to fit over the vapometer opening diameter of 63.5 mm (2.5 in). The samples were sealed onto the vapometers one of two ways. For samples performing above 4 Perm, a mechanical seal was used (figure 2a). Below 4 Perm, a wax and rosin equal weight mixture heated to 135°C (275°F) was applied as a sealant (figure 2b).

Figure 2. a) Vapometer with mechanical seal. b) Vapometer with WPP material being sealed with wax and rosin equal part mixture.

Vapometers were placed in a temperature and relative humidity controlled. Four replications were tested for each pin size and hole density in both WPP and PE. Two replicates were tested with the bag sample facing up toward the vapor source of the chamber relative humidity at 50%. Two replicates were tested with the bag sample facing down toward the vapor sink of the desiccant at 0% relative humidity. Vapometers were weighed using a Scientech ZSP350 electronic balance in uniform time increments. Relative humidity and temperature inside the chamber were recorded at each weighing. The rate of water vapor transmission (WVT) and permeance were calculated following equation 1.

Results & Discussion

The WVT, permeance and permeance per hole of the WPP and PE bagging were found for each pin size and hole density (Tables 1-3).

Table 1. Water Vapor Transmission of WPP and PE punched with various pin sizes and hole densities.

Material Type	Woven Polypropylene		Polyethylene Film	
Pin Size	0.914 mm	0.787 mm	0.914 mm	0.787 mm
	Water Vapor Transmission, g/h·m^2 (grains/h·ft^2)			
5 h/cm^2 (32 hpsi)	12.7 (18.2)	6.8 (9.8)	13.2 (19.0)	10.0 (14.4)
2.5 h/cm^2 (16 hpsi)	3.9 (5.7)	4.7 (6.7)	6.0 (8.6)	6.7 (9.6)
0.25 h/cm^2 (1.6 hpsi)	2.3 (3.3)	2.6 (3.7)	0.8 (1.1)	0.7 (1.0)
0.12 h/cm^2 (0.8 hpsi)	1.4 (2.0)	1.1 (1.6)	0.5 (0.7)	0.3 (0.4)
0.06 h/cm^2 (0.4 hpsi)	0.9 (1.3)	1.6 (2.3)	0.2 (0.4)	0.3 (0.4)
0.03 h/cm^2 (0.2 hpsi)	0.4 (0.5)	0.7 (1.0)	0.1 (0.2)	0.1 (0.2)

Table 2. Permeance performance of WPP and PE punched with various pin sizes and hole densities.

Material Type	Woven Polypropylene		Polyethylene Film	
Pin Size	0.914 mm	0.787 mm	0.914 mm	0.787 mm
	Permeance, ng/mm Hg·s·m^2 (Perm)			
5 h/cm^2 (32 hpsi)	1.46 (25.4)	0.79 (13.8)	1.53 (26.7)	1.15 (20.1)
2.5 h/cm^2 (16 hpsi)	0.45 (7.9)	0.54 (9.4)	0.68 (12.0)	0.77 (13.5)
0.25 h/cm^2 (1.6 hpsi)	0.26 (4.6)	0.30 (5.2)	0.08 (1.5)	0.08 (1.4)
0.12 h/cm^2 (0.8 hpsi)	0.16 (2.9)	0.13 (2.2)	0.05 (0.9)	0.03 (0.6)
0.06 h/cm^2 (0.4 hpsi)	0.10 (1.7)	0.18 (3.2)	0.03 (0.5)	0.03 (0.5)
0.03 h/cm^2 (0.2 hpsi)	0.04 (0.7)	0.08 (1.4)	0.02 (0.3)	0.01 (0.3)

Table 3. Permeance per hole performance of WPP and PE punched with various pin sizes and hole densities.

Material Type	Woven Polypropylene		Polyethylene Film	
Pin Size	0.914 mm	0.787 mm	0.914 mm	0.787 mm
	Permeance per Hole, ng/mm Hg·s·m^2/ hole (Perm/hole)			
5 h/cm^2 (32 hpsi)	0.009 (0.16)	0.005 (0.09)	0.010 (0.17)	0.007 (0.13)
2.5 h/cm^2 (16 hpsi)	0.006 (0.10)	0.007 (0.12)	0.009 (0.15)	0.010 (0.17)
0.25 h/cm^2 (1.6 hpsi)	0.033 (0.58)	0.038 (0.66)	0.011 (0.19)	0.010 (0.18)
0.12 h/cm^2 (0.8 hpsi)	0.042 (0.73)	0.033 (0.57)	0.014 (0.24)	0.009 (0.15)
0.06 h/cm^2 (0.4 hpsi)	0.051 (0.89)	0.093 (1.62)	0.015 (0.25)	0.015 (0.27)
0.03 h/cm^2 (0.2 hpsi)	0.043 (0.75)	0.083 (1.45)	0.016 (0.29)	0.015 (0.26)

For further discussion of WVT, permeance and permeance per hole, the inch-pound units will be used as the cotton industry is more familiar with the that unit system.

Figure 3 illustrates the graphical analysis of water vapor transmission for polyethylene film punched with 0.914 mm pins. Each line represents the average weight gain of four sample replications. The slope of each line gives the WVT. From Table 1 the values for WVT are 19.0, 8.6, 1.1, 0.7, 0.4 and 0.2, respectively for decreasing hole density. The permeance and permeance per hole for the same conditions is shown in figure 4. Permeance increases with increasing hole density as expected. Permeance per hole, on the other hand, increases with decreasing hole density.

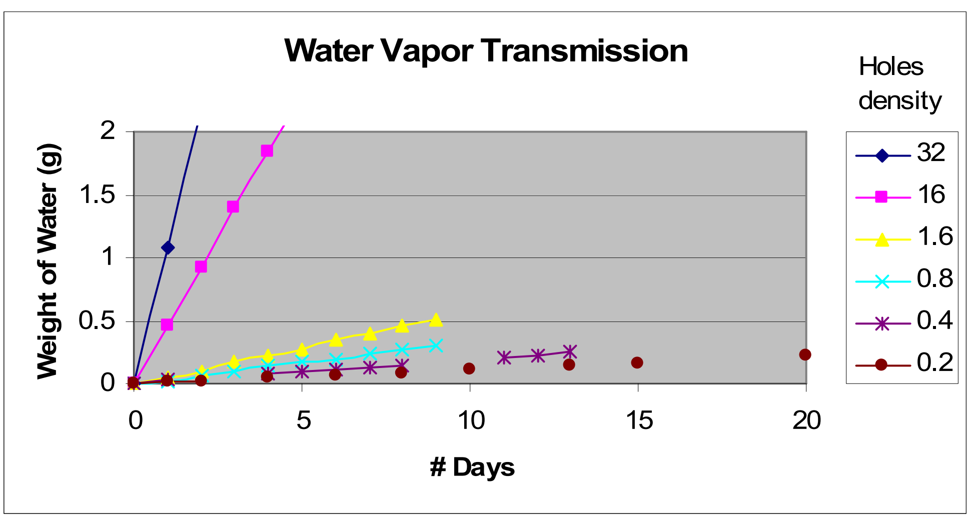

Figure 3. Water vapor transmission for polyethylene film bagging punched with pin size 0.914 mm.

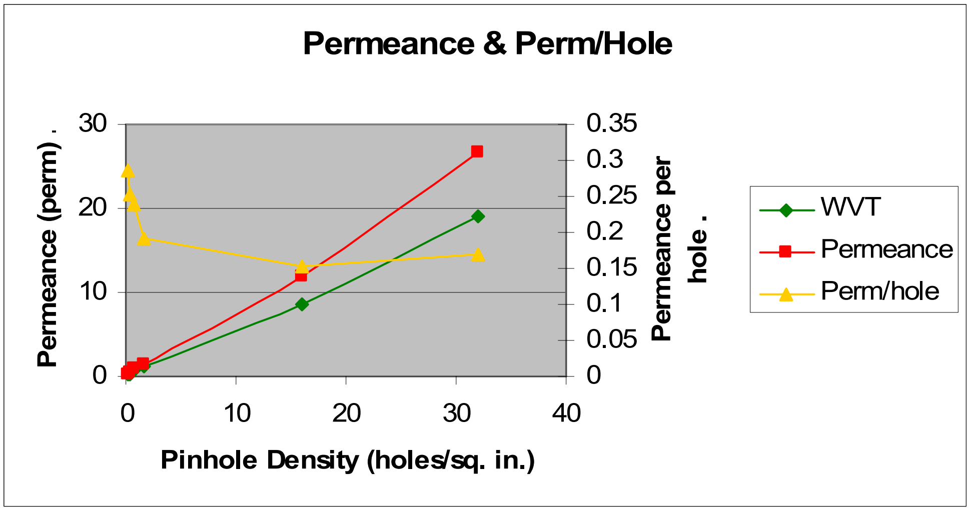

Figure 4. Permeance and permeance per hole for polyethylene film bagging punched with pin size 0.914 mm.

At the beginning of this study, it was thought that a permeance performance similar to housewrap material would be desirable. Housewrap material is used as a moisture barrier to prevent water from entering into drywall and other construction materials of a house. However, housewrap is perforated to allow water vapor that builds up inside a house to escape to the atmosphere. Housewrap is thought to perform around 10 to 20 Perms. The samples with hole densities of 32 and 16 perform within or close to that 10 to 20 Perm range.

Manufacturers of polyethylene film bagging have performed trials where they have perforated bagging and tested the material for tensile strength characteristics. According to the manufacturers, the tensile strength decreases dramatically when hole density increases. For this reason, further analysis and testing will be focused on low hole densities.

Permeance for all materials, pin sizes, and hole densities 1.6 and below are combined in one graph on Figure 5. The permeance performance of WPP is higher than PE at all hole densities shown. The WPP material with 0.4 hpsi showed significantly higher permeance than expected. This was due to the nature of the materials. WPP is a tape construction with a laminate. The laminate can crack or rupture where tapes intersect. Therefore, the WPP material can develop holes in addition to those created with pins. Care was taken during this study to select areas of the WPP material that were void of cracks and holes when cutting samples. However, after inspection of the samples used for the 0.4 hpsi density, additional cracks in the laminate were observed. These cracks are the likely cause of the higher than expected permeance. The inherently higher permeance of WPP than PE can be attributed to such cracks. As a film material, PE is not expected to develop cracks.

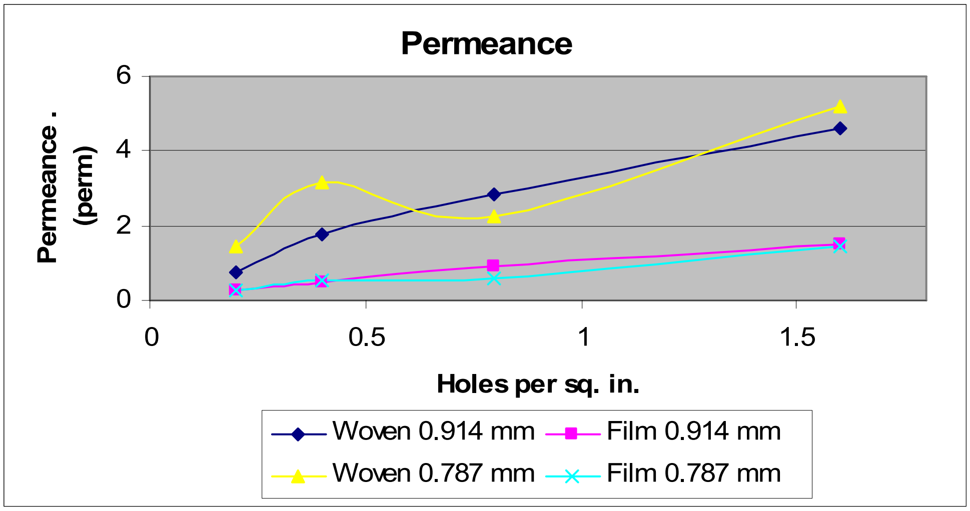

Figure 5. Permeance performance of WPP and PE versus hole density for both pin sizes.

Pin size does not seem to play a significant role in permeance performance for either WPP or PE (figure 6). These polyolefins have excellent elastic characteristics. After the pin is retracted, the elastic nature of the bags may provide some "healing" ability so that the hole created recovers and shrinks in size. A larger pin size may overcome the reversible deformation so that a larger hole and higher permeance performance can be accomplished.

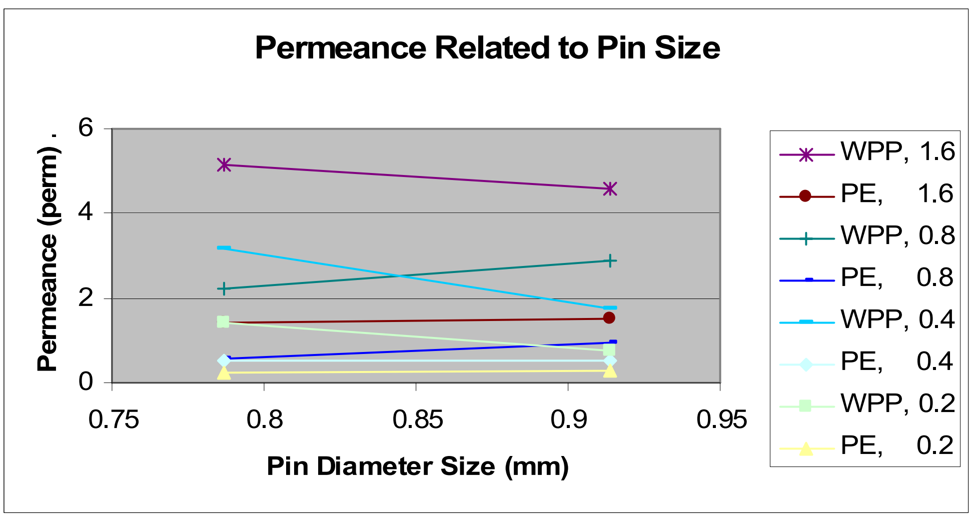

Figure 6. Permeance performance of WPP and PE versus pin size for four hole densities.

The permeance per pinhole performance is shown in figure 7. The permeance per pinhole decreases with increasing pinhole density for both WPP and PE. The permeance per pinhole is higher for WPP compared to PE, for reasons discussed previously. The baseline permeance performance of WPP and PE begin to override the permeance due to the created pinholes at the lower pinhole densities. Although not performed following the ASTM E 96 standard, preliminary testing with the vapometers did show the unmodified WPP material to have a higher permeance than the unmodified PE material.

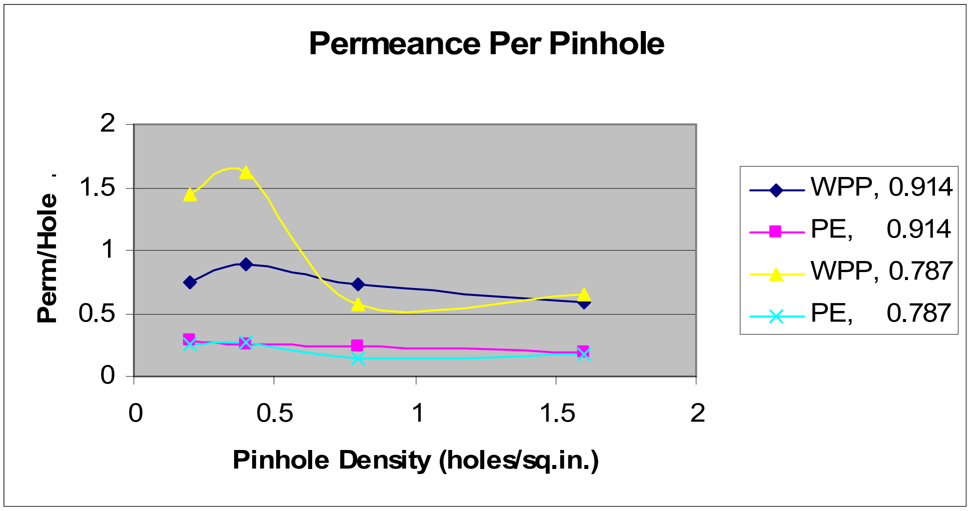

Figure 7. Permeance per pinhole performance of WPP and PE versus pinhole density for two pin sizes.

Conclusions

Several conclusions can be drawn from these tests so far:

- Woven polypropylene (WPP) performs at a higher permeance than polyethylene film (PE).
- Permeance per pinhole decreases with increasing pinhole density.
- No significant difference in permeance between holes resulting from 0.787 mm and 0.914 mm pin sizes.

Future Work

Additional water vapor transmission testing will be performed on WPP and PE in the lower pinhole densities. It may be beneficial to test with the larger 1.58 mm and smaller 0.356 mm pin sizes to determine if larger holes can be created and if smaller holes result in similar permeance performance.

Testing on full-scale cotton bales is desirable to determine if permeance performance on the bale will be similar to laboratory studies. PE and especially WPP material may differ greatly after the bagging is stretched over cotton bales. With the stretching of WPP, the intersecting tapes may prove to elongate at a higher rate than the laminate, causing the laminate to crack. More cracks will result in higher water vapor transmission. Staff at the USDA-ARS Cotton Ginning Laboratory in Stoneville, Mississippi, will cooperate in further testing.

Acknowledgements

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